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# Memo

*DATE:* *October 17, 2003*

*TO:* RHIC E-Coolers

*FROM:* *Ady Hershcovitch*

*SUBJECT:* **Minutes of the October 17, 2003 Meeting**

Present: Ilan Ben-Zvi, Andrew Burrill, Xiangyun Chang, Alexei Fedotov, Michael Harrison, Ady Hershcovitch, Jorg Kewisch, Vladimir Litvinenko, William Mackay, Stephen Peggs, Thomas Roser, Triveni Srinivasan-Rao, Vitaly Yakimenko.

Topics discussed: Optical Stochastic Cooling and progress in photocathode development.

**Optical Stochastic Cooling**: Vitaly opened the meeting with a report on the Optical Cooling Workshop. He started by comparing "conventional" stochastic cooling to optical stochastic cooling. The big advantage of optical stochastic cooling over conventional stochastic cooling is the cooling rate. In the case of interest to us conventional stochastic cooling using a 5-cm wavelength has a cooling time of about 10 hours. Optical stochastic cooling with a wavelength of 12 micrometers can, theoretical achieve, the same cooling in 11 sec! With a reasonable power level cooling time of 1 hour can be expected.

In a practical optical stochastic cooling scheme, the present objective is to use a $CaGeAS_2$ crystal parametric amplifier. In this scheme, optical power is to be generated with 5.3-micrometer double frequency $CO_2$ laser and a 3-cm long $CaGeAS_2$ crystal, which can achieve a gain of $3x10^5$. For each 4 mm, the cadmium-gallium-arsenic crystal can achieve an e-folding amplification. The near-term objective is to show the feasibility of the cadmium-gallium-arsenic crystal. With LDRD funding test of 8 mm crystal with 200 Watt 5.3 micron radiation is to be performed. Expected amplification is a factor of 70. The main topic that needs to be addressed is absorption/thermal issue, i.e., minimizing absorption and cooling the crystal. 10% absorption has been achieved. The aim is to reduce it by a factor of 5. Another remaining issue is to find a commercial 10 MHz, 200 W mode-lock CO or $CO_2$ pump laser.

In an answer to Mike's question regarding the bandwidth, Vitaly replies that there various modes of operation varying from as low as 2% to as high as 10% bandwidth. By comparison RF systems have 50% bandwidth (however, this bandwidth is at a frequency that about 5000 times higher, making a huge absolute bandwidth). Jorg asked a question regarding the filtering of the 10 Hz RHIC ring oscillation. There is no clear answer to that however since the amplitude is smaller than the beam size it is not expected to affect the optics. Finally Mike asked about the merit of electron beam cooling if optical stochastic cooling has this great potential. Vitaly pointed out that like conventional stochastic cooling, optical stochastic cooling is most efficient in cooling the tails of the particle distribution. Its cooling capability is constant with emittance, while electron beam cooling is efficient against IBS, and its cooling rate increases as the emittance decreases, i.e., the two are complimentary. The main impact of optical stochastic cooling would be to reduce the needed electron beam by a factor of 3.

Attached is a copy Vitaly's viewgraphs.

**Photocathode**: in an answer to Thomas' question on the status of the deposition system Andrew Burrill gave a short report on deposition experiments that were performed. Deposition uniformity rose with time. It improved from 30% to 5% over the 2.5-cm cathode that is needed for the 2-cm laser spot size. Quantum efficiency of 2.5% was reached at a current of 16 microampere. Though it later dropped to 3 microampere.

Andy showed the quantum efficiency as a function of laser wavelength between 365 and 550 nm. Best results were obtained at the shorter wavelengths, where a quantum efficiency of 15% was achieved at 365 nm versus 2.5% quantum efficiency achieved at 550 nm. Ilan asked about which is the practical laser. Going to the 3$^{rd}$ harmonic of the YAG laser, the power reduces to 30%, additionally as Vladimir pointed out there is a reduction in the number of photons. But, overall, there is a factor of two gain at the shorter wavelengths. Triveni pointed out that another advantage is that at shorter wavelengths the quantum efficiency is less sensitive to wavelength variations.

Deposition was performed with antimony and cesium. Thomas asked about potassium. Andy replied that the potassium detector did not function. Ilan said that if potassium can be avoided, it is better for the system as a whole. Finally Ady suggested exploring the use of a porous molybdenum cathode for vapor injection through its back. There were questions about the viability of such a porous cathode in an RF system. Ilan pointed out that at Maryland work is being done with porous cathodes.

# Status of the Optical Stochastic Cooling for RHIC

October 16, 2003

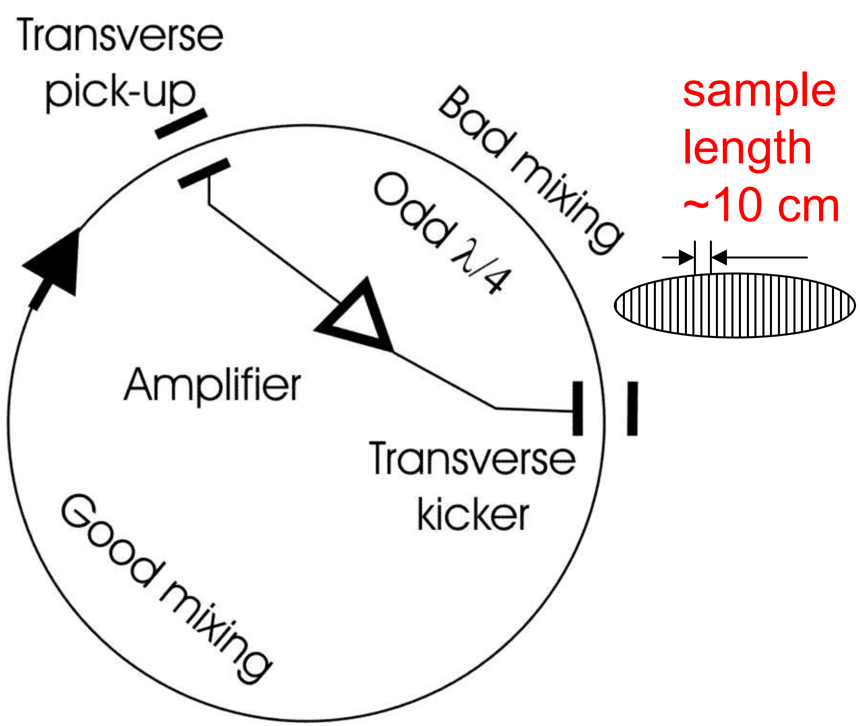
# Basic idea

## Stochastic Cooling

$$N_s = \frac{\lambda}{3\Gamma}\frac{N_i}{\sigma_l}$$

In practice $n_d = 20 n_d^{ideal}$

λ~ 5 cm => **ideal** bandwidth limited cooling time τ~2.5 hrs.

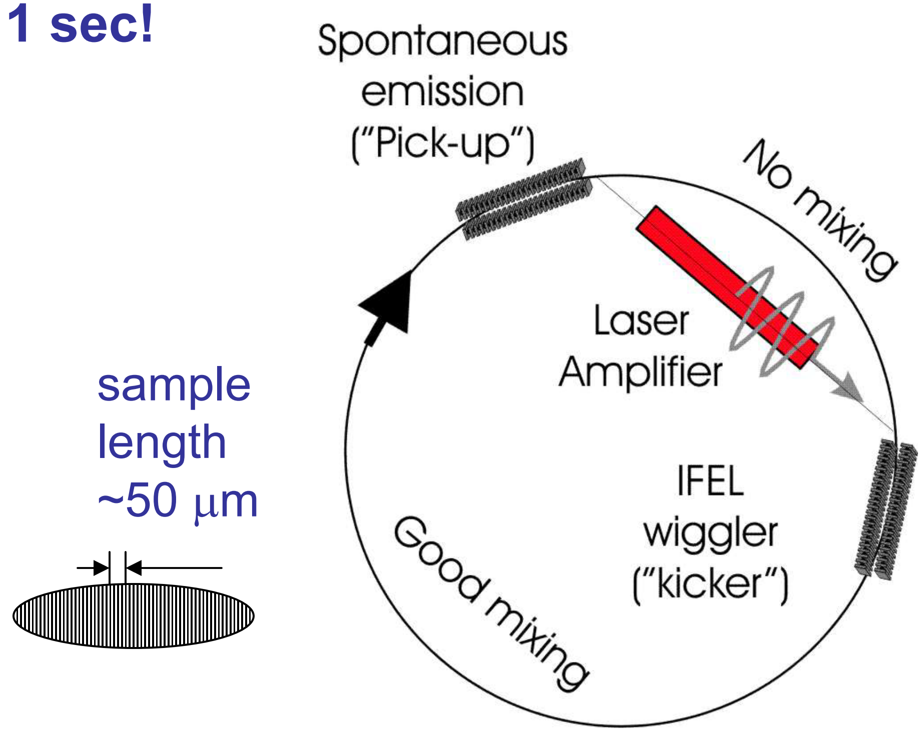



## Optical Stochastic Cooling

$$n_d \approx 2eN_s$$

In practice time is amplifier limited

λ~ 12 μm => power limited cooling time τ~1 hr with 16 W; bandwidth limited **τ~11 sec!**



# Bandwidth limited calculations:

$$\tau := 2e \cdot \frac{\lambda}{\Gamma} \frac{Ni}{3 \cdot lb} \cdot \frac{C}{c}$$

$$2 \cdot e \cdot \frac{5 \cdot cm}{0.5} \cdot \frac{1.2 \cdot 10^{9}}{3 \cdot 30 \cdot cm} \cdot \frac{3834 \cdot m}{2.998 \cdot 10^{8} \cdot \frac{m}{s}} \cdot \frac{1}{hr} = 2.575$$

$$2 \cdot e \cdot \frac{12 micron}{0.1} \cdot \frac{1.2 \cdot 10^{9}}{3 \cdot 30 \cdot cm} \cdot \frac{3834 \cdot m}{2.998 \cdot 10^{8} \cdot \frac{m}{s}} = 11.124 s$$

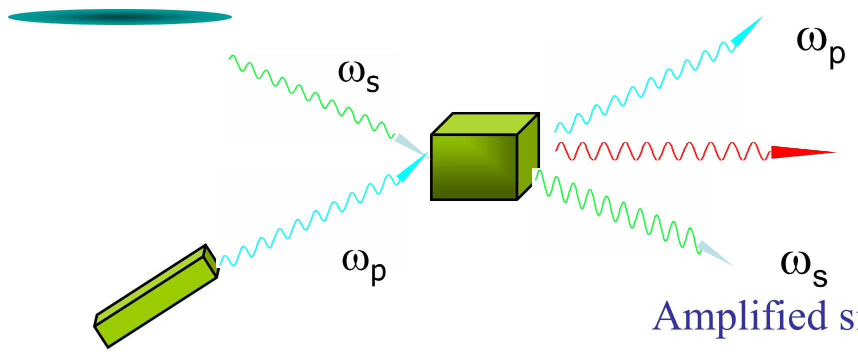
# OSC VS. Electron cooling

- OSC favorites the beam tails (time transient method): $^{dA}/_{dt} \sim \sin(k\,A)$
- Usually limited by the power of the optical amplifier.
- Low signal with low $\gamma$ beams
- Match of the high field wiggler period and laser wavelength is required.
- ***Efficient against tails.***

- Electron cooling is efficient on beam core $^{dA}/_{dt} \sim A^{-3/2}$
- Limited by electron current / recombination compromise.
- Cooling time slows with beam energy, but in the same way as IBS.
- ***Efficient against IBS.***

# Parametric Amplifier

ion beam




Amplified signal

Pump Laser

Nonlinear crystal $CdGeAs_2$

$d_{36} = 236$ pm/V

$\omega_i = \omega_p - \omega_s;$

$k_p = k_s + k_i$

$\lambda_{pump} = 5.3\ \mu m$ (Doubled frequency $CO_2$ laser)

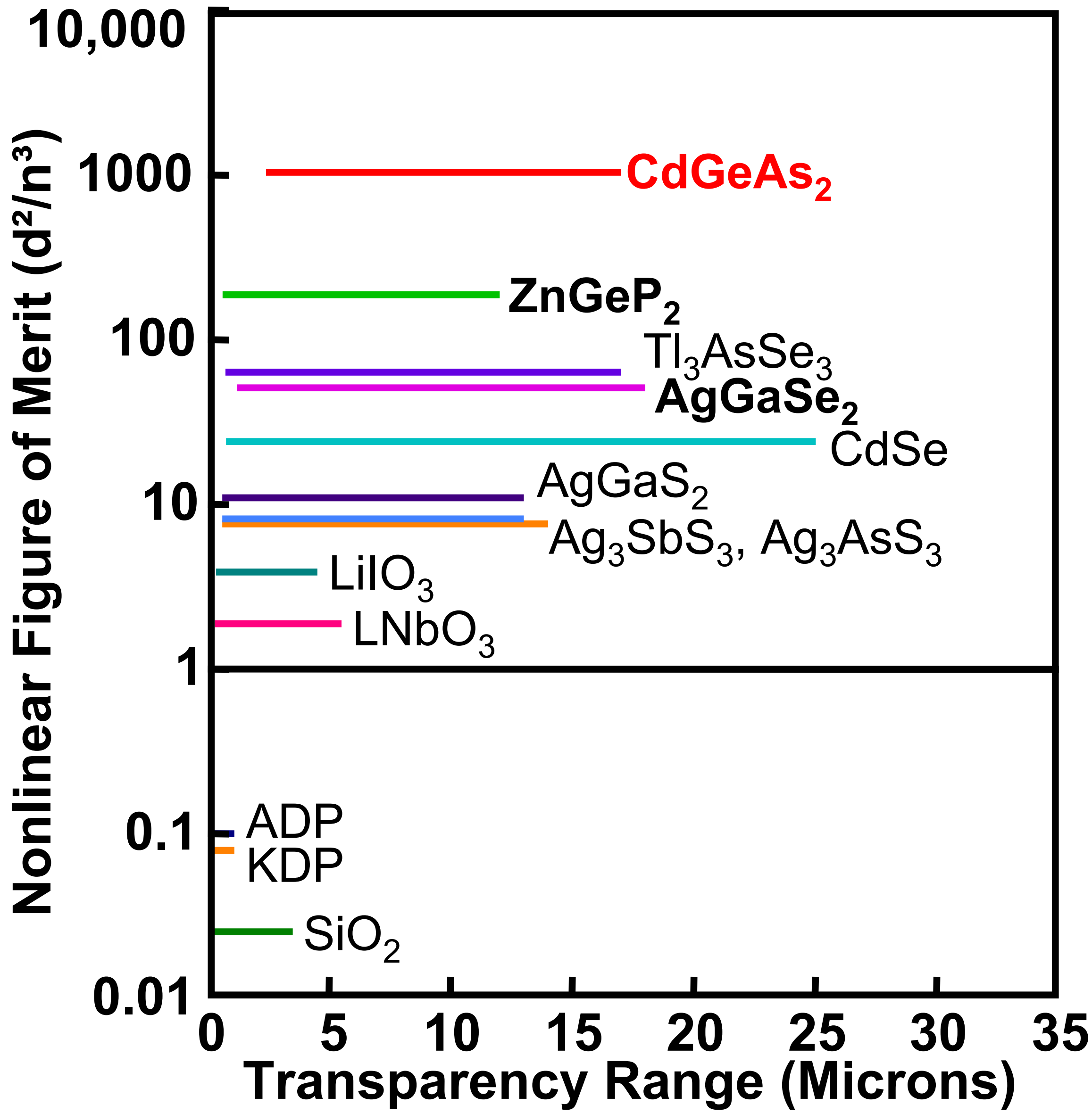
$\lambda_{signal} = 12\ \mu m$

$P_L = 20\ MW/cm^2$ (damage threshold, conservative)

$l = 4$ mm (*e* times gain length)

3 cm length crystal $\rightarrow$ intensity gain $3\ 10^5$

## $CdGeAs_2$ has long been known as a promising nonlinear optical material for IR frequency conversion



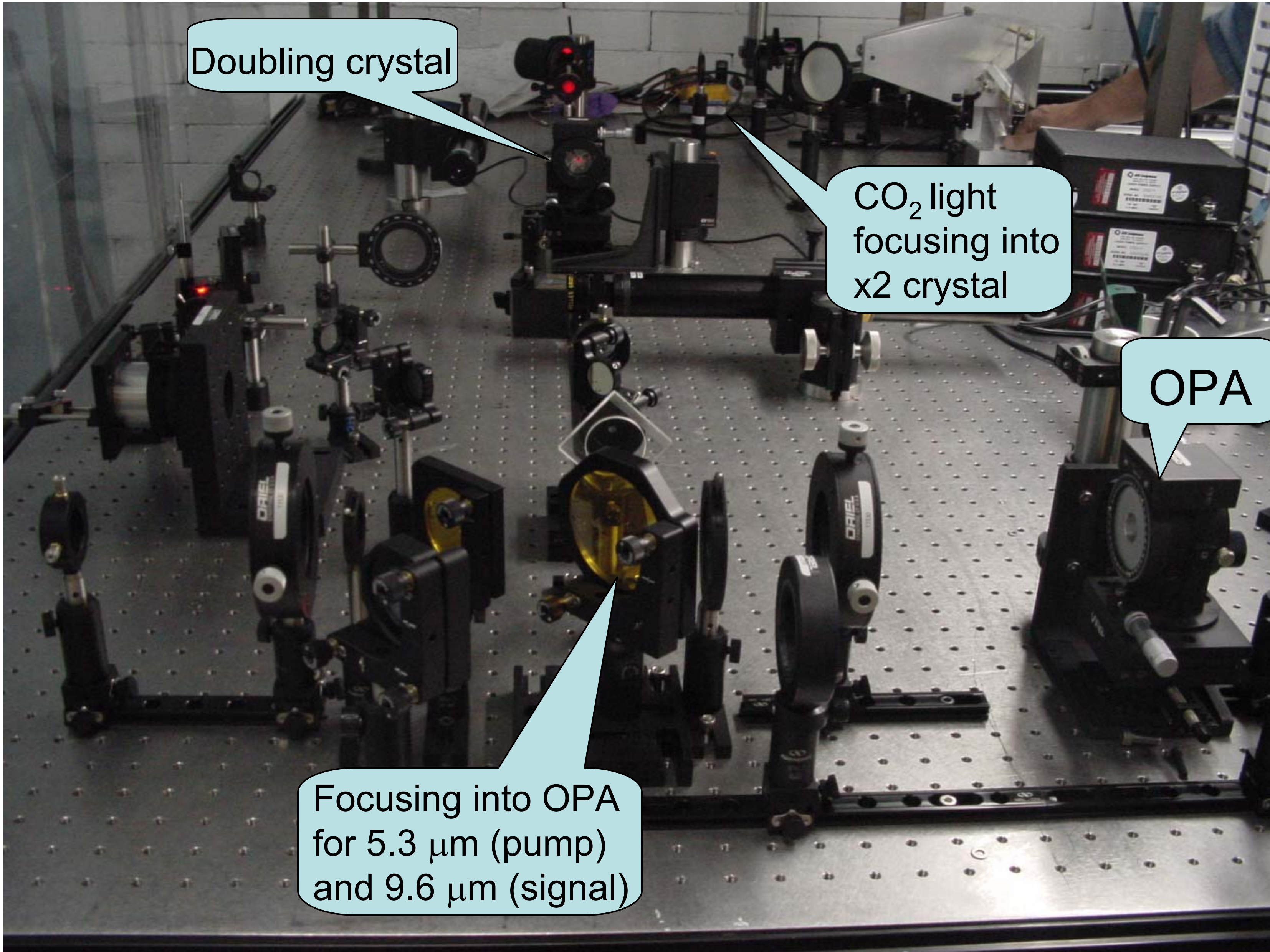

**Advantages**

- Highest Nonlinear Coefficient of any known compound ($d_{14}$ = 236 pm/V)
- Long Wavelength IR Cut-off (17 microns)
- Large Birefringence allows for Broad Phase-Matching Range
- Adequate Thermal Conductivity (.042 W/cmK) for high power applications

**Disadvantages**

- Anisotropic Thermal Expansion (a-axis 15x> c-axis), cracking
- Defect-related Absorption Loss

# Current status of OPA



# OSC can be divided into 5 main components

- Optical amplifier (Optical Parametric Amplifier (OPA): 3 cm long CdGeAs2 crystal, cooled to 77K for better thermal conductivity and transparency) (experimental tests within 1 year)
- Pump source for OPA (mode locked CO or CO-2 laser operating at 10 MHz with 200W output at 5.3micron) (forgotten technology, design within 1 year)
- RHIC lattice modification design (exist only understanding what needs to be done)
- Diagnostics (needs to be developed)
- Pair (per ring) of 10T 3 meter long wigglers and modified RHIC bending magnets (to allow wiggler light extraction) (existing technology, need cost estimate)

# Agenda (day 1)

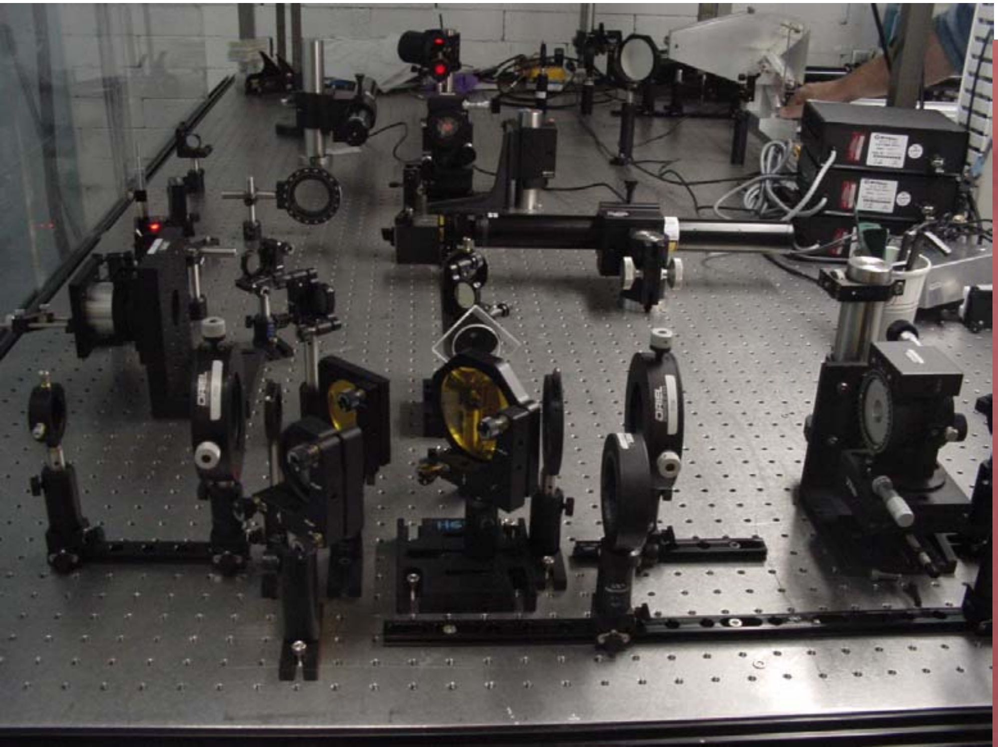
- 9:00-9:30, Vitaly Yakimenko, Meeting charge, budget, …
- 9:30-10:00, Marcus Babzien, Calculations $CdGeAs_2$ based amplifier
- 10:00-10:30, *Coffee break*
- 10:30-11:00, Igor Pavlishin, Parametric amplifier test scheme
- 11:00-12:00 Igor Pavlishin, Tour of the test stand
- 12:00-13:00 *Lunch break*
- 13:00-14:00 Igor Pogorelsky, Mode locked pump laser for PA.
- 14:00-14:30 Peter Schunemann $CdGeAs_2$ Recent progress
  14:00-15:00 Marcus Babzien, Heat related issues
- 15:00-15:30 *Tea time*
- 15:30-17:30 Free discussion
- 19:00 *Host free dinner*

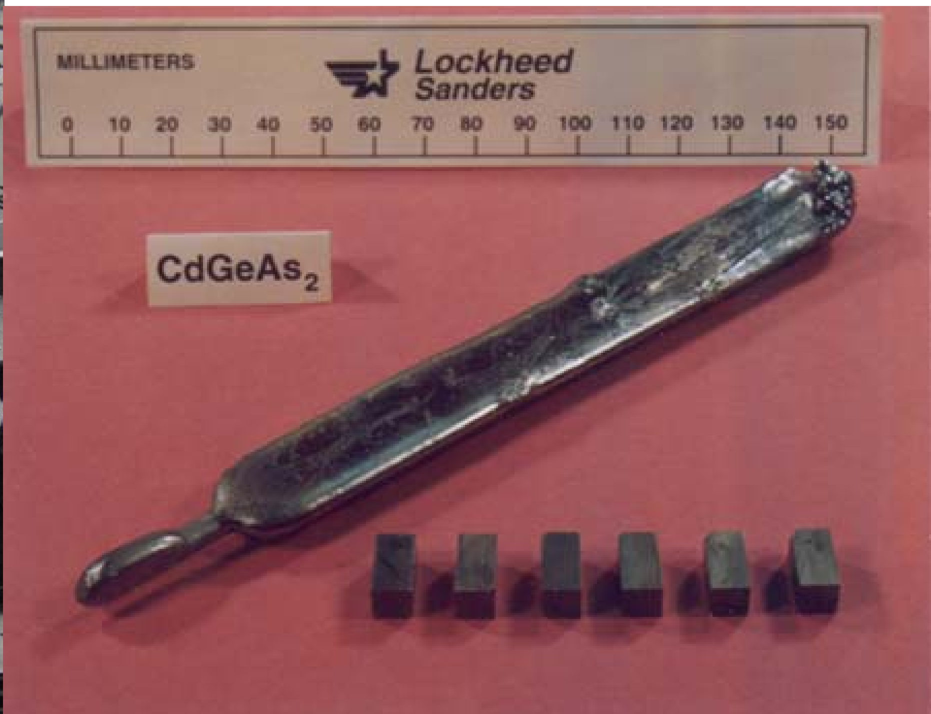
# Agenda (day 2)

- 9:00-9:30, Sasha Zholents, An introduction: bringing everyone to speed on what we know now
- 9:30-10:00, Weishi Wan, Studied examples and used computational tools.
- 10:00-10:30, Vitaly Yakimenko, A proposed bypass for RHIC.,
- 10:30-10:45 Dejan Trbojevic, Installation of the OSC undulators at RHIC, possibilities and limitation
- 10:45-12:00 All participants, List of what should be done, priorities, man power.
- 12:00-13:00 *Lunch break*
- 13:00-15:00 Wrap-up, individual discussions.

# OPA status

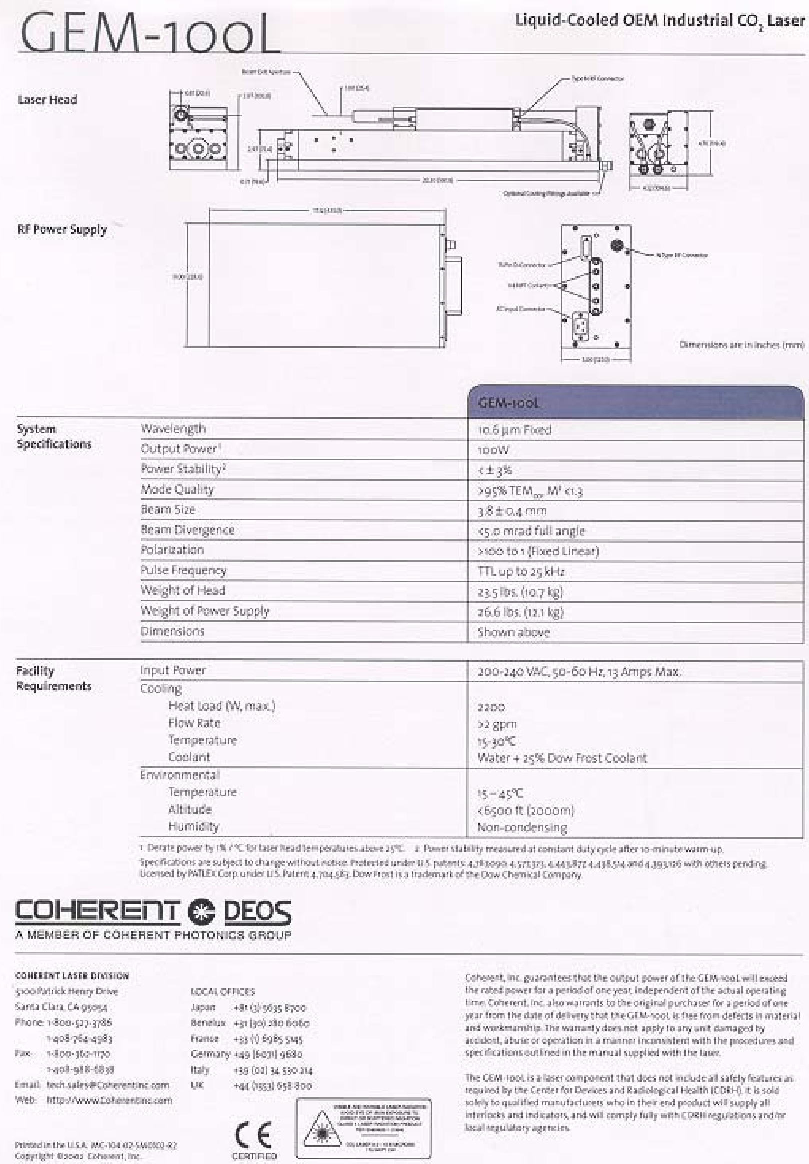
- Tests of the OPA Operation in a single pulse mode expected to be finished within 2 months (covered by LDRD)
- Operation of OPA in the “RHIC” duty factor expected to be tested using output of JLAB’s FEL as the pump source (covered by LDRD, can use engineer for thermal calculations)





# Pump source

- Design of the pump laser would be finished this year under LDRD
- Components for mode locked, low power seed laser estimated as 100K and about same for amplifier (There are no funding for this from current LDRD)

GEM-100L

Liquid-Cooled OEM Industrial $CO_2$ Laser

Laser Head

RF Power Supply

Dimensions are in inches (mm)

| | | GEM-100L |
|---|---|---|
| System Specifications | Wavelength | 10.6 µm Fixed |
| | Output Power[1] | 100W |
| | Power Stability[2] | < ± 3% |
| | Mode Quality | >95% $TEM_{00}$, $M^2$ <1.3 |
| | Beam Size | 3.8 ± 0.4 mm |
| | Beam Divergence | <5.0 mrad full angle |
| | Polarization | >100 to 1 (Fixed Linear) |
| | Pulse Frequency | TTL up to 25 kHz |
| | Weight of Head | 23.5 lbs. (10.7 kg) |
| | Weight of Power Supply | 26.6 lbs. (12.1 kg) |
| | Dimensions | Shown above |
| Facility Requirements | Input Power | 200-240 VAC, 50-60 Hz, 13 Amps Max. |
| | Cooling | |
| | Heat Load (W, max.) | 2200 |
| | Flow Rate | >2 gpm |
| | Temperature | 15-30°C |
| | Coolant | Water + 25% Dow Frost Coolant |
| | Environmental | |
| | Temperature | 15 – 45°C |
| | Altitude | <6500 ft (2000m) |
| | Humidity | Non-condensing |

1 Derate power by 1% / °C for laser head temperatures above 25°C. 2 Power stability measured at constant duty cycle after 10-minute warm-up.

Specifications are subject to change without notice. Protected under U.S. patents 4,283,090 4,571,373, 4,443,877 4,438,514 and 4,393,506 with others pending. Licensed by PATLEX Corp. under U.S. Patent 4,704,583. Dow Frost is a trademark of the Dow Chemical Company.

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CE CERTIFIED

Coherent, Inc. guarantees that the output power of the GEM-100L will exceed the rated power for a period of one year, independent of the actual operating time. Coherent, Inc. also warrants to the original purchaser for a period of one year from the date of delivery that the GEM-100L is free from defects in material and workmanship. The warranty does not apply to any unit damaged by accident, abuse or operation in a manner inconsistent with the procedures and specifications outlined in the manual supplied with the laser.

The GEM-100L is a laser component that does not include all safety features as required by the Center for Devices and Radiological Health (CDRH). It is sold solely to qualified manufacturers who in their end product will supply all interlocks and indicators, and will comply fully with CDRH regulations and/or local regulatory agencies.

# RHIC bypass

- Lattice modification are needed to satisfy :
  - Time of flight difference between light and ions of the order of 15 cm.
  - Very small time delay from pickup to kicker wiggler.
- Possible light bypass locations are from “dummy” (arc missing dipole for dispersion suppression) to “dummy” either through IP or through arc (require beating of the dispersion in this arc). (Engineering involvement is needed)
- Dynamic aperture, lattice errors … calculation are needed.
- Experiment to verify lattice performance at fraction of 10 micron is needed (light interference or beam noise preservation can be used to verify R56)

# Diagnostics

- There are ideas, but need more work
  - Interference of the edge radiation
  - Preservation of the noise signal in the beam after passing bypass
  - …

# Wigglers

- Wigglers are known technology. Fist pass on gap, price … can be useful.
- Regular RHIC magnet need to be split in order to get light out. (First look on price …)

# Possible external collaborations

- LBL
- JLAB
- BAE Systems